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SOME TESTS OF ELECTRICALLY OPERATED DEEP WELL PUMPS¹

BY P. S. BIEGLER AND I. W. FISK

About a year ago the writers presented a paper before the Illinois Section of the American Water Works Association, setting forth the results of tests of pumping units at the plant of the Champaign-Urbana Water Company, including a study of the operation of a cam-type, motor-driven pump at various speeds above and below normal. In the present paper are given the results of tests showing the performance of a crank-type, motor-operated pump of recent design for a wide range of speeds and for a considerable range of head for each speed. The pump is of the belt-driven double-action deep-well type; having a bore of $6\frac{1}{4}$ inches, a stroke of 18 inches and a speed of approximately 26 revolutions per minute.

For the measurement of discharge, a calibrated orifice bucket was used and extreme care was exercised in getting accurate results by having one man watch the gage constantly, averaging the readings during each stage of the tests. The depth of water in the well was determined by means of an electrical contact device sensitive to a variation of water level of 1 inch, and a polyphase rotating standard watthour-meter made possible very accurate readings of power intake of the driving motor in spite of the fluctuating nature of the load. All of this apparatus was fully described in the paper referred to above, published in the JOURNAL in 1917.

In order to investigate the performance of the pumping unit at various heads, a valve was inserted in the discharge pipe of the pump, and, by restricting the opening, it was possible to increase the effective head against which the pump was operating, for each size of pulley, i.e., for each pump speed.

In table 1 are shown the complete experimental data and a few words of explanation should make clear the method of arriving at

¹ Read before the Illinois Section at Urbana, April 16, 1918. Certain tables and illustrations in the original paper giving details of the tests have not been reproduced.

TABLE 1
Test of an electrically driven deep well pump

CURRENT SUPPLIED		PUMP		TOTAL HEAD	DISCHARGE, GALS. PER MINUTE			OUTPUT	EFFICIENCIES		
		Pulley	Rev. per minute		Theoretical	Actual	Slip		Motor	Pump	Over-all
<i>kw.</i>	<i>h.p.</i>	<i>inches</i>		<i>feet</i>				<i>h.p.</i>	<i>p.c.</i>	<i>p.c.</i>	<i>p.c.</i>
3.725	4.92	4	19.65	148.3	94.3	82.5	11.8	3.09	82.8	75.7	62.8
3.815	5.11	4	19.65	148.3	94.3	82.5	11.8	3.09	82.9	73.0	60.5
2.765	5.045	4	19.65	148.3	94.3	82.5	11.8	3.09	82.8	73.9	61.4
4.31	5.78	4	19.58	177.4	94.0	82.0	12.0	3.67	84.0	75.5	63.5
4.317	5.782	4	19.52	177.4	93.7	83.0	10.7	3.72	84.0	76.5	64.4
4.292	5.755	4	19.56	177.4	93.9	82.0	11.9	3.67	84.0	76.0	63.8
4.89	6.555	4	19.68	207.1	94.5	81.5	11.5	4.26	84.9	76.5	65.0
4.90	6.565	4	19.56	207.1	93.9	81.7	12.2	4.27	84.9	76.7	65.0
5.49	7.36	4	19.68	236.7	94.5	80.5	14.0	4.81	85.8	76.2	65.3
5.51	7.38	4	19.68	236.7	94.5	81.0	13.0	4.83	85.8	76.6	65.5
4.77	6.39	5	24.15	153.5	115.8	102.5	13.3	3.97	84.8	73.2	62.1
4.735	6.35	5	24.15	153.8	115.8	102.0	13.8	3.955	84.8	74.2	62.3
5.37	7.2	5	23.86	182.8	114.5	100.3	14.2	4.625	85.7	75.0	64.25
5.39	7.225	5	24.00	182.8	115.2	101.0	14.2	4.67	85.7	75.5	64.6
6.13	8.22	5	23.8	212.8	114.3	100.0	14.3	5.37	86.0	76.0	65.3
6.105	8.195	5	23.92	212.8	114.8	100.5	14.3	5.375	86.0	76.3	65.6
6.92	9.28	5	23.86	242.8	114.5	98.7	15.8	6.06	86.2	75.7	65.3
6.9	9.25	5	23.73	242.8	114.0	98.7	15.3	6.06	86.2	76.0	65.5
5.28	7.08	5½	26.0	152.7	124.8	111.0	13.8	4.28	85.3	70.9	60.45
5.28	7.08	5½	26.1	153.5	125.3	111.0	14.3	4.305	85.3	71.3	60.8
5.94	7.96	5½	25.8	183.4	123.8	109.2	14.6	5.045	86.0	73.7	63.4
5.94	7.96	5½	25.9	183.6	124.4	109.5	14.9	5.07	86.0	74.1	63.7
6.72	9.01	5½	25.7	213.7	123.4	109.4	14.0	5.895	86.2	75.8	63.4
6.74	9.04	5½	25.8	213.8	123.8	109.5	14.3	5.905	86.2	75.6	65.4
7.57	10.14	5½	25.6	243.8	122.9	108.8	14.1	6.7	86.0	76.6	66.1
6.24	8.38	6½	30.65	156.9	147.0	131.3	15.7	5.21	86.1	72.2	62.2
6.33	8.49	6½	30.8	157.0	147.8	131.3	16.5	5.22	86.1	71.4	61.5
7.05	9.45	6½	30.6	185.0	146.9	128.5	18.4	6.00	86.2	73.6	63.5
7.06	9.465	6½	30.5	185.0	146.4	128.8	17.6	6.01	86.2	73.6	63.5
8.06	10.81	6½	30.8	216.3	147.8	127.5	20.3	6.96	86.0	74.7	64.3
8.00	10.72	6½	30.4	216.5	145.9	127.2	18.7	6.95	86.0	75.2	64.8
9.05	12.13	6½	30.8	246.5	147.8	126.3	21.5	7.86	85.8	75.2	64.75
9.07	12.17	6½	30.8	246.5	147.8	126.3	21.5	7.86	85.8	75.2	64.5
6.72	9.01	7	32.75	163.3	157.0	139.5	17.5	5.76	86.2	74.1	64.0
6.75	9.05	7	32.75	163.3	157.0	140.3	16.7	5.82	86.2	74.6	64.3
7.58	10.17	7	32.75	188.9	157.0	138.5	18.5	6.60	86.1	75.3	65.0
7.55	10.12	7	32.6	188.9	156.2	138.5	17.7	6.60	86.1	75.7	65.2
8.57	11.50	7	32.5	218.8	156.0	137.5	18.5	7.57	85.9	75.5	65.8
8.55	11.46	7	32.4	218.8	155.4	137.5	17.9	7.57	85.9	75.8	66.2
9.62	12.90	7	31.7	248.7	152.1	135.5	16.6	8.50	85.3	77.2	66.0
9.61	12.89	7	31.7	248.7	152.1	135.5	16.6	8.51	85.3	77.5	66.2
7.90	10.58	8	36.85	167.0	177.0	159.0	18.0	6.70	86.0	73.5	63.3
7.92	10.60	8	37.10	167.0	178.0	160.0	18.0	6.73	86.0	73.7	63.5
7.96	10.66	8	37.10	167.5	178.0	160.5	17.5	6.78	86.0	73.9	63.5
8.85	11.43	8	36.78	192.3	176.5	158.5	18.0	7.67	85.8	78.0	67.0
8.73	11.68	8	36.78	192.3	176.5	158.7	17.8	7.685	85.8	76.5	66.0
8.74	11.70	8	36.78	192.3	176.5	158.8	17.7	7.70	85.8	76.7	65.8
9.98	13.36	8	36.78	222.0	176.5	157.5	19.9	8.82	85.0	77.7	66.0
10.02	13.42	8	36.30	222.0	174.2	156.5	17.7	8.77	85.0	77.0	65.3
11.30	15.13	8	36.30	251.6	174.2	155.5	19.7	9.87	83.8	77.8	65.2

the results calculated from the data. The efficiency of the driving motor at normal voltage and frequency for various values of power intake was plotted and the mechanical power delivered to the pump could be obtained from this curve. The efficiency curve was obtained from careful laboratory tests of this particular motor and is not based on approximate data supplied by any manufacturer. In calculating the theoretical discharge, the full piston displacement was assumed, and the volume of the piston rod was neglected.

The results for each of six different speeds were plotted separately so that it was possible to study the effect of changing head on pump performance for any speed. It may be observed in general that the speed of the pump did not change appreciably with a given pulley, except where the motor was overloaded. The motor used in these tests was an induction motor with short-circuited rotor, giving substantially constant speed up to full load. The slip, for each speed, increases with the head, apparently in a straight line relation, as might be expected, and, in consequence, the actual discharge falls off, approximately in a straight line, as the head increases.

Regarding pump efficiency, it is of interest to observe that this item increases in all cases as the head is increased. This follows from the fact that, for a constant speed, the power delivered by the pump increases nearly in direct proportion to the head, while the losses in the pump change but little. The mechanical friction is approximately constant for a given speed and the slip increases more slowly than the discharge. The over-all efficiency curves were nearly parallel to the corresponding pump efficiencies because the driving motor has a flat efficiency characteristic, except that a falling off of over-all efficiency occurs at high heads on account of the considerable overload on the motor.

After examining the curves for each speed, the data were assembled in a different manner to show all speeds with change of head in one group of curves, figure 1. It is seen in this figure that the speed of the pumping unit remains substantially constant for a given pulley, the greatest change being with the largest pulleys. The slip curves for various speeds, figure 1, are more or less alike, showing an increase with head, but they apparently do not increase with the speed for the reason that the water flows past the valves due to the head, or pressure, and independent of the speed. The broken line shows average slip for all heads. It should be borne in

mind that slip is obtained from the difference between theoretical and actual discharge. If an error of 1 per cent is made in the

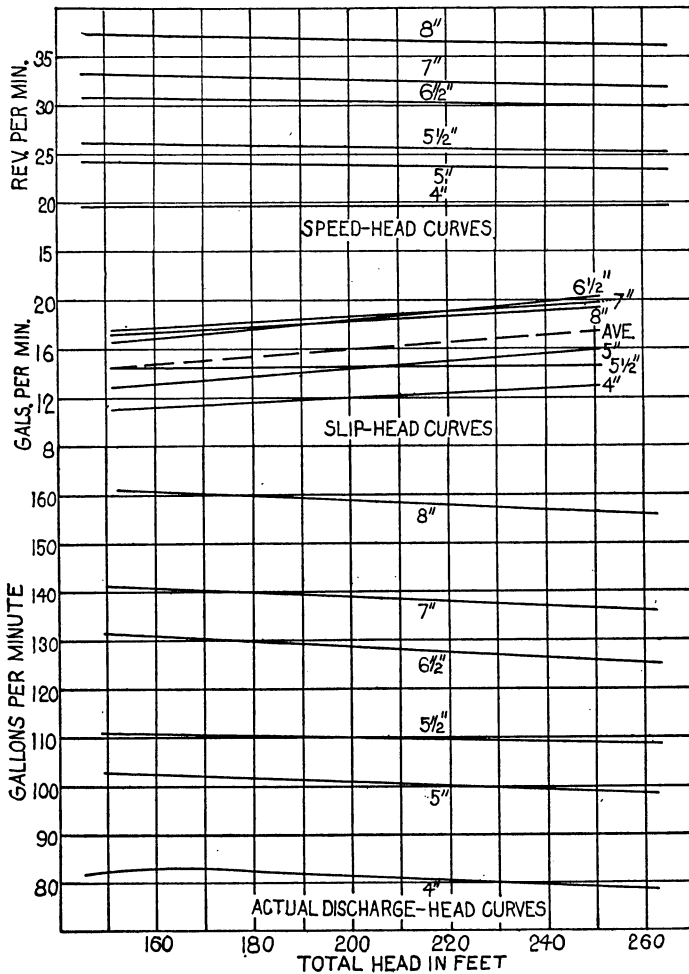


FIG. 1. CURVES OF PERFORMANCE OF CRANK-TYPE DOUBLE-ACTION DEEP WELL PUMP. FIGURES ON CURVES SHOW SIZE OF PULLEY USED

determination of each of these quantities, the error in slip may be greater than 3 gallons. So, in spite of the greatest possible care exercised in obtaining discharge data, the individual slip curves are

not entirely rational. The broken line, however, undoubtedly gives a reliable idea of the variation of slip with head.

The actual discharge curves, figure 1, fall off faster at high speeds, on account of overloading the motor. All are seen to be approximately straight lines.

Pump efficiency and over-all efficiency curves, plotted against head, are shown assembled in figure 2 and average efficiencies are

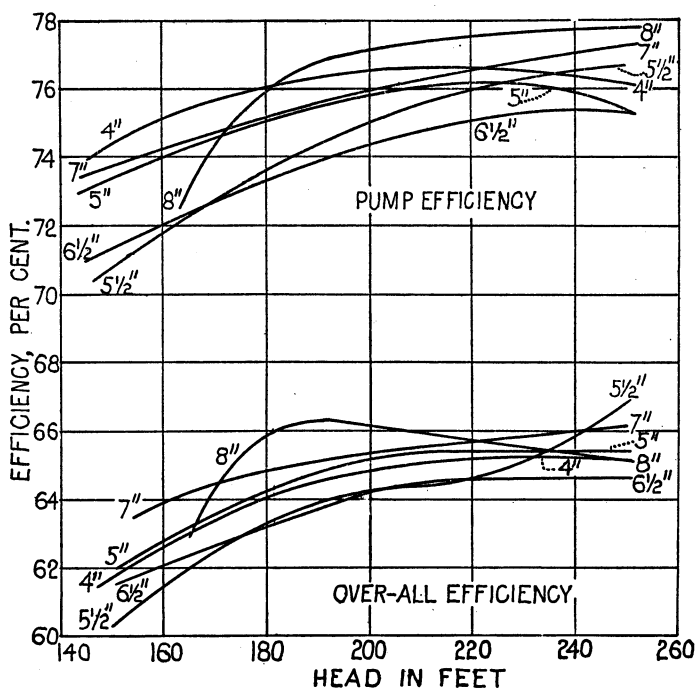


FIG. 2. EFFICIENCY CURVES OF CRANK-TYPE DOUBLE-ACTION DEEP WELL PUMP. FIGURES ON CURVES SHOW SIZE OF PULLEY USED

given in table 2. There is an increase in pump efficiency, for a given head, principally because the slip does not increase appreciably with speed, and the over-all efficiency curves also rise with speed.

Regarding the efficiency-head curves, it is evident that pump efficiency increases approximately in direct proportion to the head. As already pointed out, this is due to the fact that mechanical

friction is substantially independent of the head and slip increases slowly with the head. By plotting all the theoretical discharge records in relation to head, table 3 can be derived from the curves for the calculation of the average percentage of slip.

Although the head is increased from 160 to 240, table 3, or 50 per cent, the average slip increases but 17 per cent, thus accounting for the greatly improved pump efficiency at high head.

Over-all efficiency curves, figure 2, are practically parallel to the pump efficiency curves, until the motor is overloaded. The motor used for these tests was 20 per cent overloaded with the 8-inch pulley and at 240 feet head. Obviously the over-all efficiency curve is dependent upon the size and design of driving motor, and the over-all efficiency curves should be practically parallel to pump curves in all practical cases where the motor is not overloaded.

TABLE 2
Average pump and over-all efficiencies

Head, feet.....	160	180	200	220	240
Efficiency, per cent					
Pump.....	73.0	74.4	75.5	75.5	76.6
Over-all.....	62.0	64.1	65.0	66.0	65.5

TABLE 3
Average theoretical discharges and slips

Head, feet,.....	160	180	200	220	240
Theoretical discharge, gallons per minute.....	136.0	135.6	135.2	134.8	134.3
Slip, gallons per minute.....	14.8	15.6	15.9	16.4	17.4
Average slip, percentage.....	10.88	11.5	11.73	12.15	12.95

Throughout the range of speed and head, the pump operated smoothly. There was no knock or hammer, even though the pump was considerably overloaded at high head and speed. Just what the effect would be for long-continued operation at high head and speed has not been determined at the time this paper is presented. It is safe to assume, however, that the pump up-keep would be considerably increased under conditions of maximum loading. For a large increase in speed, the authors believe this added repair expense would more than offset the gain in efficiency. In case several electrically operated pumps are in use in any system, the pumps may be speeded up to advantage in case one pump fails. Again, during a dry, hot season, it might pay to gear the pumps up

for greater output for a considerable period of time. Also, where deep wells are difficult to locate and drill, it is evident that the cost of pumping per thousand gallons might be less and thus the over-all plant efficiency might be increased by operating at speeds above normal instead of drilling and equipping new wells.

It might be well to call attention, at this time, to the possibility of meeting some very difficult war conditions by increasing the speed of pumps. While the development of some communities, due to war industries, may outgrow the pumping equipment, it is probable that delivery of this machinery will become increasingly difficult; so that extraordinary measures must be taken by the water supply companies to give satisfactory service. Higher pump speeds, at least temporarily, may prove the solution of these acute problems. The increased efficiency of reciprocating pumping units at higher speeds is also of importance when the cost of coal and the necessity of saving coal are taken into consideration.

Each individual case, of course, has its own solution, and in this article are given the results of tests made on one particular pump. These tests show results for average operating conditions, as they were made, not in a laboratory, but under working conditions in the field. The results should, therefore, be of interest to operators.